(02) IN/34 0114

MARANGONI EFFECTS ON NEAR-BUBBLE MICROSCALE TRANSPORT DURING BOILING OF BINARY FLUID MIXTURES

C. Sun, V. P. Carey
Department of Mechanical Engineering, University of California, Berkeley, CA 94704

B. Motil
NASA Glenn Research Center, Cleveland, OH 44315

ABSTRACT

In earlier investigations (see Ahmed, et al. [1]), Marangoni effects were observed to be the dominant mechanism of boiling transport in 2-propanol/water mixtures under reduced gravity conditions. In this investigation we have examined the mechanisms of binary mixture boiling by exploring the transport near a single bubble generated in a binary mixture between a heated surface and cold surface. The temperature field created in the liquid around the bubble produces vaporization over the portion of its interface near the heated surface and condensation over portions of its interface near the cold surface. Experiments were conducted using different mixtures of water and 2-propanol under 1g conditions and under reduced gravity conditions aboard the KC135 aircraft. Since 2-propanol is more volatile than water, there is a lower concentration of 2-propanol near the hot surface and a higher concentration of 2-propanol near the cold plate relative to the bulk quantity. This difference in interface concentration gives rise to strong Marangoni effects that move liquid toward the hot plate in the near bubble region for 2-propanol and water mixtures. In the experiments in this study, the pressure of the test system was maintained at about 5 kPa to achieve the full spectrum of boiling behavior (nucleate boiling, critical heat flux and film boiling) at low temperature and heat flux levels. Heat transfer data and visual documentation of the bubble shape were extracted from the experimental results.

In the 1-g experiments at moderate to high heat flux levels, the bubble was observed to grow into a mushroom shape with a larger top portion near the cold plate due to the buoyancy effect. The shape of the bubble was somewhat affected by the cold plate subcooling and the superheat of the heated surface. At low superheat levels for the heated surface, several active nucleation sites were observed, and the vapor stems from them merged to form a larger bubble. The generation rate of vapor is moderate in this regime and the bubble shape is cylindrical in appearance. In some instances, the bubble interface appeared to oscillate. At higher applied heat flux levels, the top of the bubble became larger, apparently to provide more condensing interface area adjacent to the cold plate. Increasing the applied heat flux ultimately led to dry-out of the heated surface, with conditions just prior to dryout corresponding to the maximum heat flux (CHF). A more stable bubble was observed when the system attained the minimum heat flux (for film boiling). In this regime, most of the surface under the bottom of the bubble was dry with nucleate boiling sometimes occuring around the contact perimeter of the bubble at heated surface. Figure 1 shows a typical bubble in this regime.

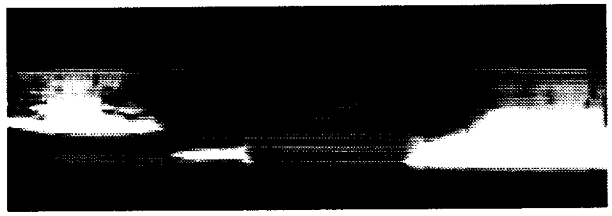

Fig. 1. Bubble profile for 2-propanol mole fraction of 0.015, with gap =6.4 mm, pressure = 4.04 kPa, ΔT_c = 2.73°, ΔT_h = 99.79°, T_{bulk} = 27.5° C, q" = 728.7 kW/m^2.

Different variations (e.g. gap between two plates, molar concentration of the liquid mixture) of the experiments were examined to determine parametric effects on the boiling process and to determine the best conditions for the KC135 reduced gravity tests. Variation of the gap was found to have a minor impact on the CHF. However, reducing the gap between the hot and cold surface was observed to significantly reduce the minimum heat flux for fixed molar concentration of 2-propanol.

In the reduced gravity experiments aboard the KC135 aircraft, the bubble formed in the 6.4 mm gap was generally cylindrical or barrel shaped and it increased its extent laterally as the surface superheat increased. In reduced gravity experiments, dryout of the heated surface under the bubble was observed to occur at a lower superheated temperature than for 1g conditions. Observed features of the boiling process and heat transfer data under reduced gravity will be discussed in detail. The results of the reduced gravity experiments will also be compared to those obtained in comparable 1g experiments.

In tandem with the experiments we are also developing a computational model of the transport in the liquid surrounding the bubble during the boiling process. The computational model uses a level set method [2] to model motion of the interface. It will incorporate a macroscale treatment of the transport in the liquid gap between the surfaces and a microscale treatment of transport in the regions between the bubble interface and the solid surfaces. The features of the model will be described in detail. Future research directions suggested by the results to date will also be discussed.

REFERENCES

[1] Ahmed, S. and Carey, V.P., 1998, "Effects of Gravity on Boiling of Binary Fluid Mixtures," *Int. Journal of Heat and Mass Transfer*, Vol. 41, pp. 2469-2483.
[2] Sethian, J. A., 1996, *Level Set Methods*, Cambridge University Press, Cambridge, U.K.

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C. Sun, V.P. Carey

Department of Mechanical Engineering, University of California at Berkeley

B. Motil

NASA Glenn Research Center, Cleveland, OH

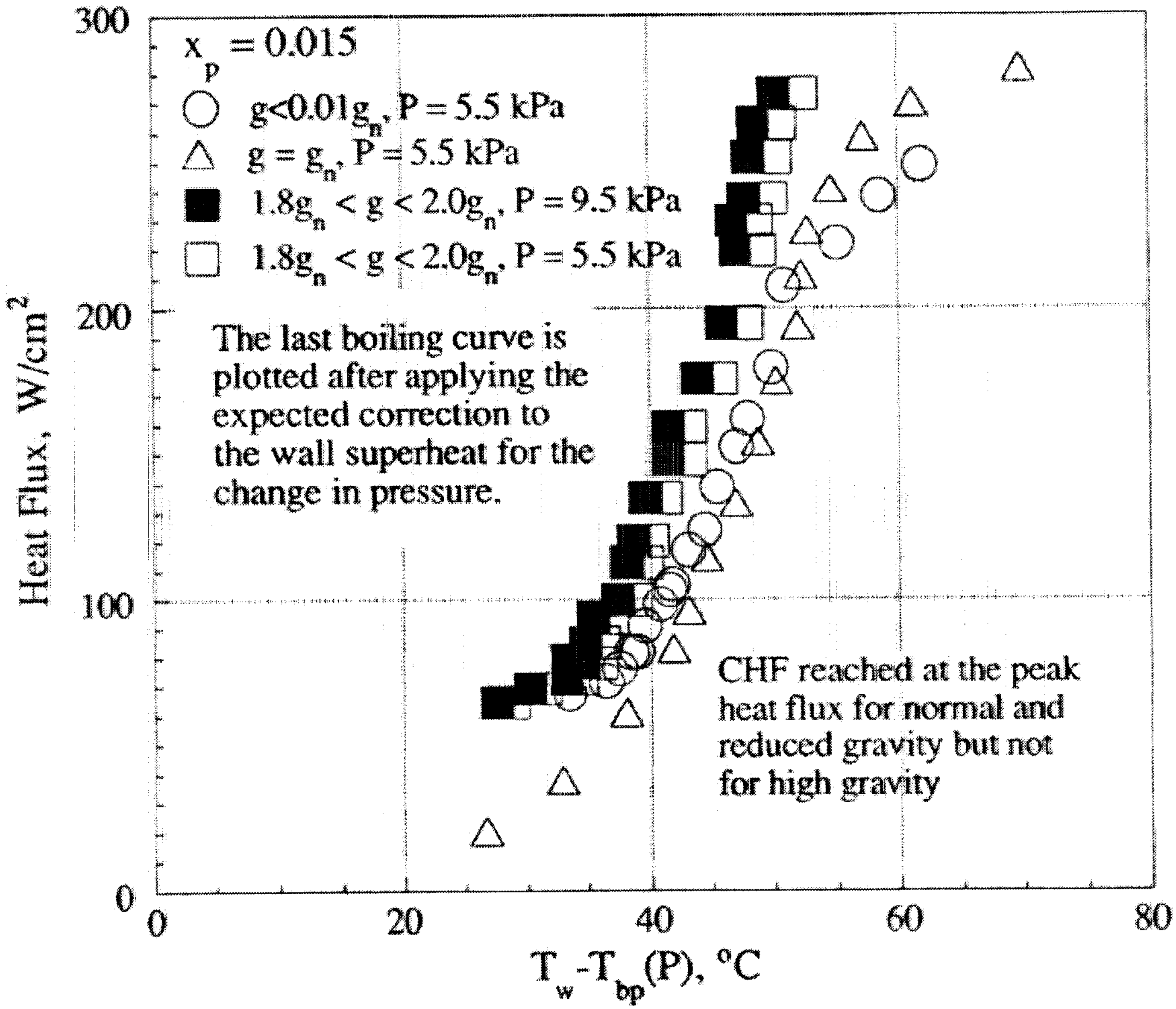
Outline

Background

Experiments

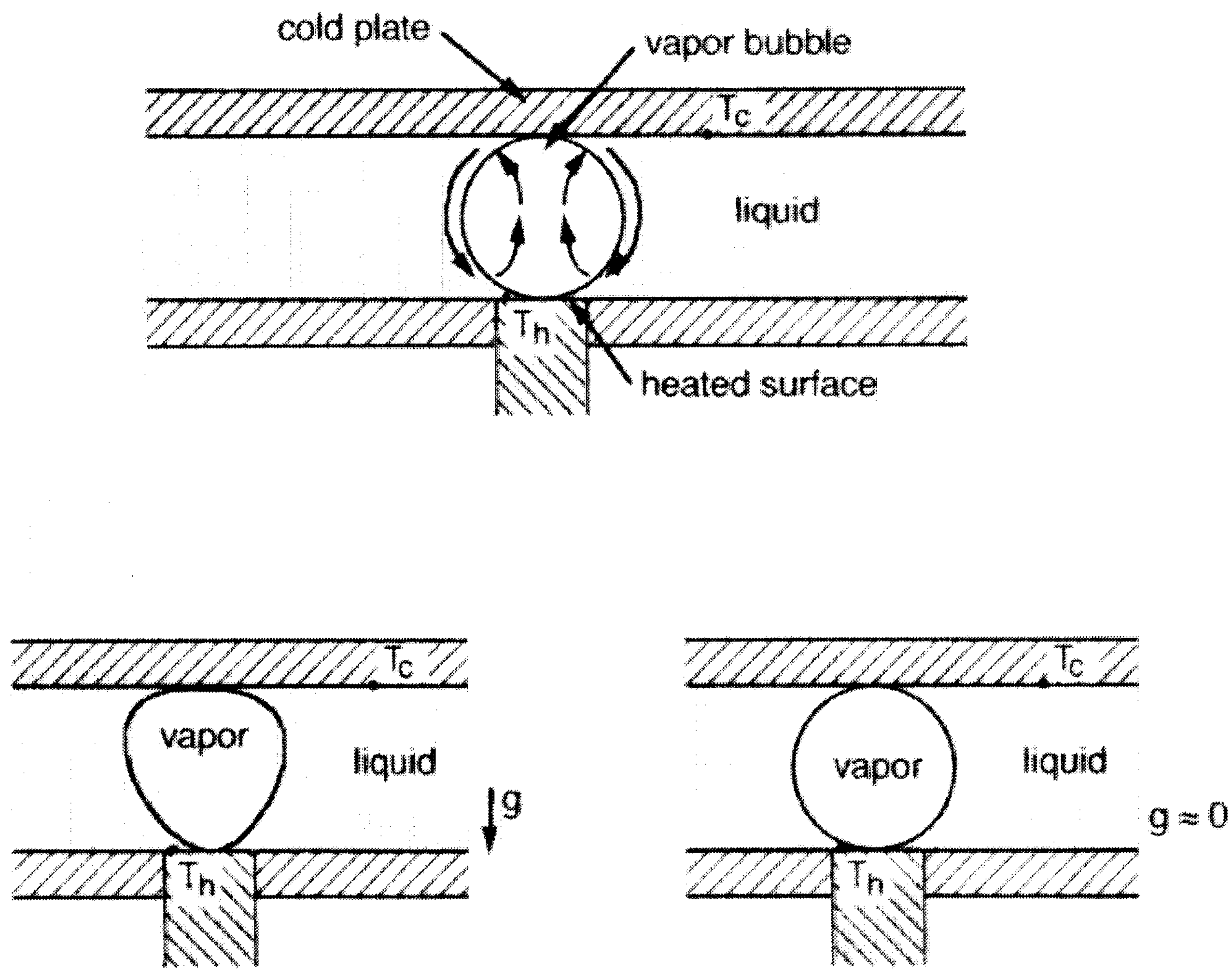
Results

Conclusions and Future Work



Effect of gravity on the boiling of water/2-propanol mixture for x_p=0.015.

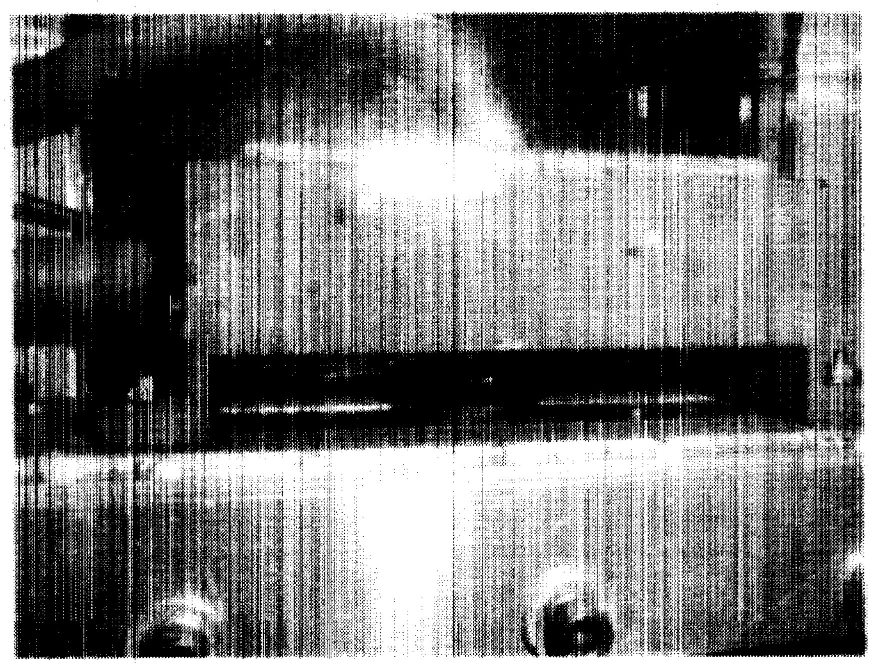
Marangoni Effects on Near Bubble Transport



Multiphase Transport Laboratory, August 2000

Marangoni Effects on Near Bubble Transport

- Test section with stationary bubble



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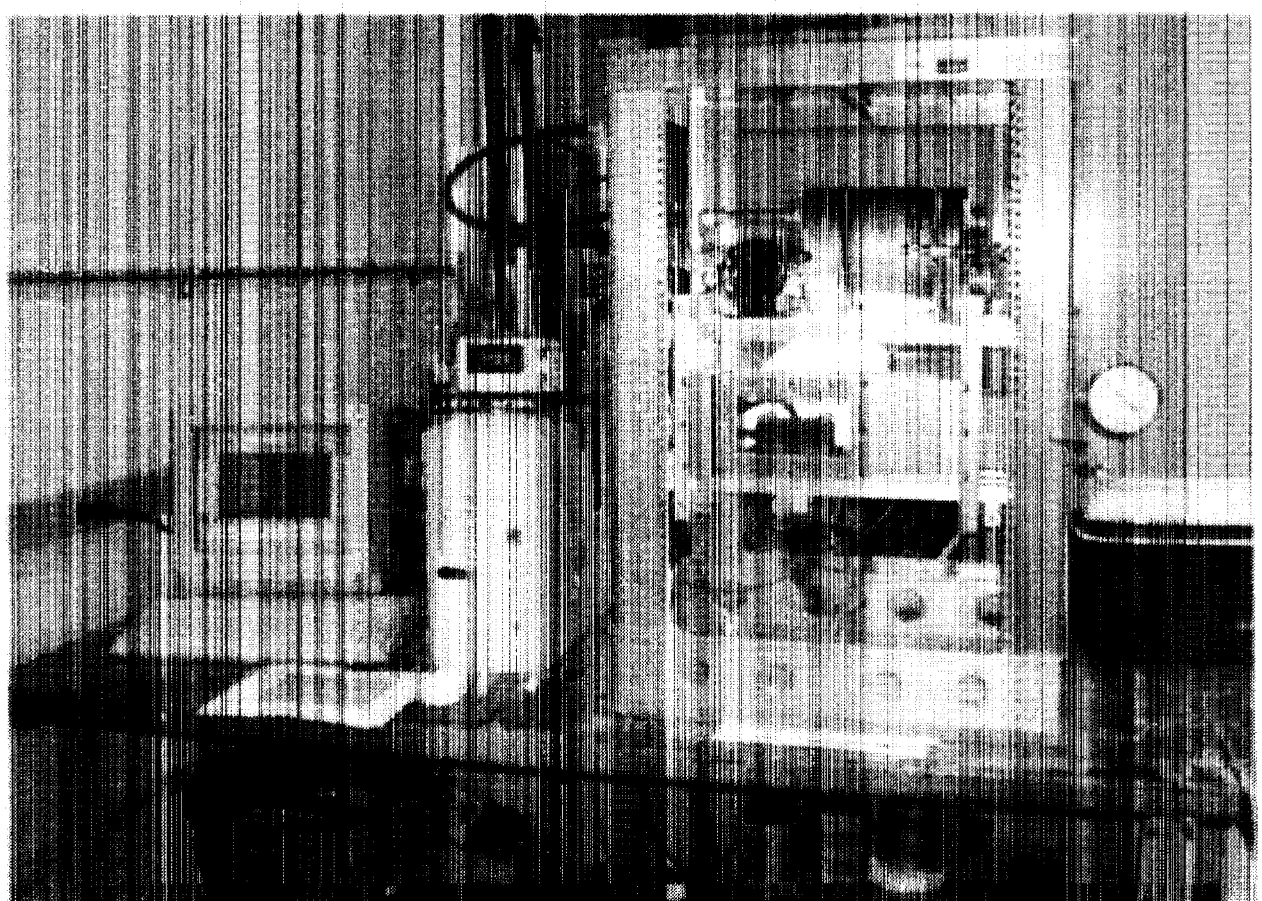
Marangoni Effects on Near Bubble Transport

- Test system



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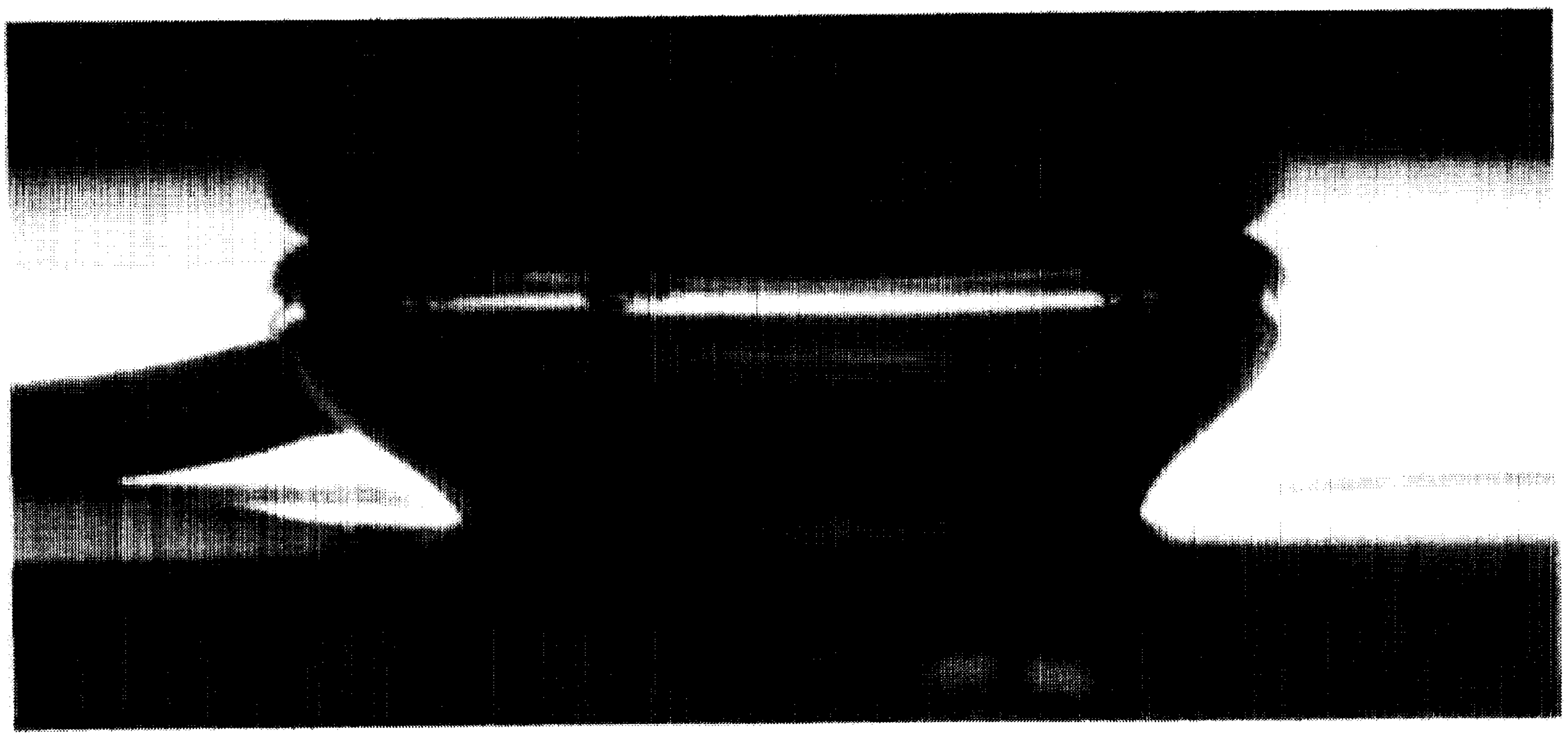
Marangoni Effects on Near Bubble Transport

- pure water at 4 kPa,
- wall superheat = 34 °C, coldplate subcooling = 15 °C



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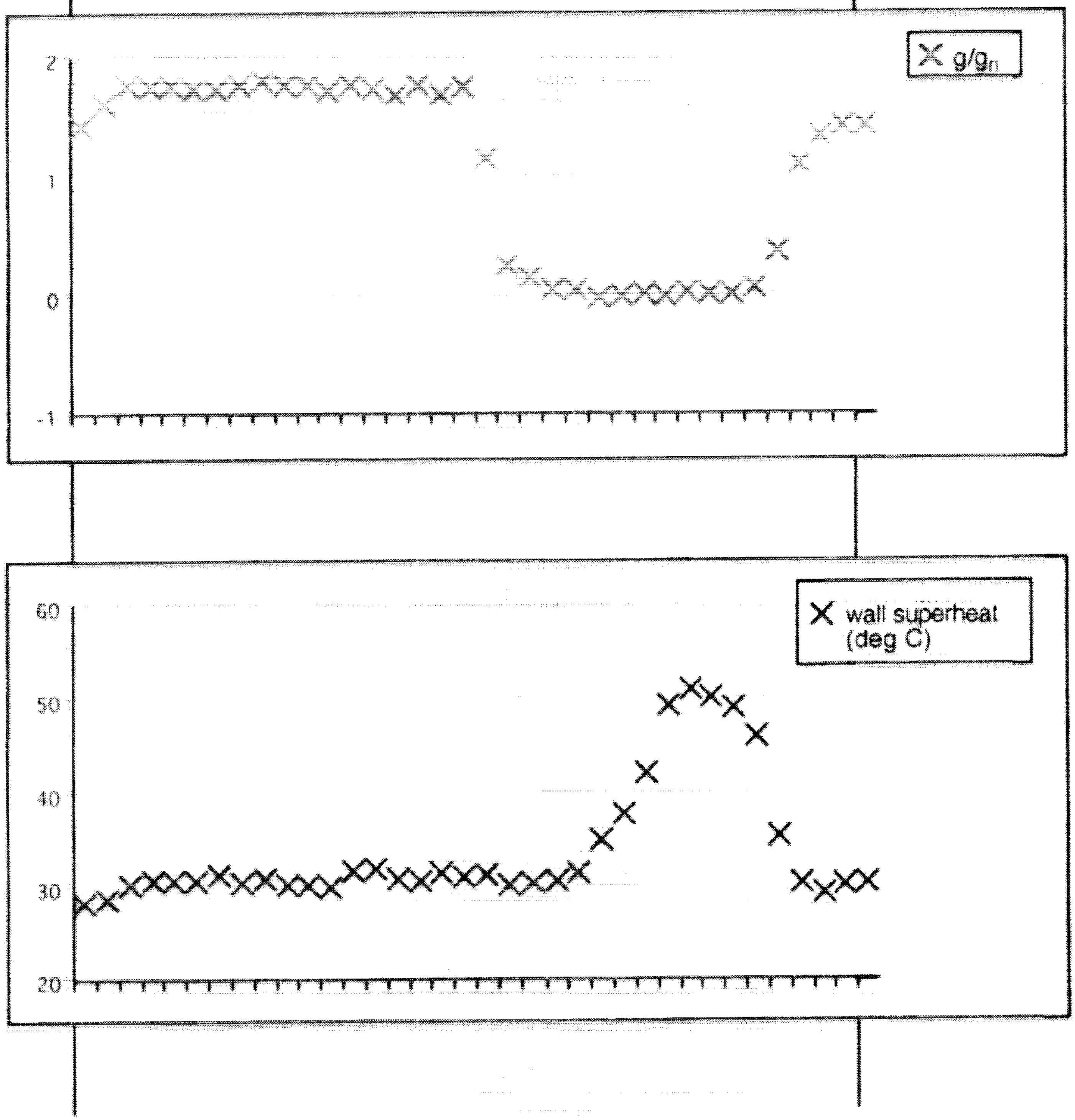
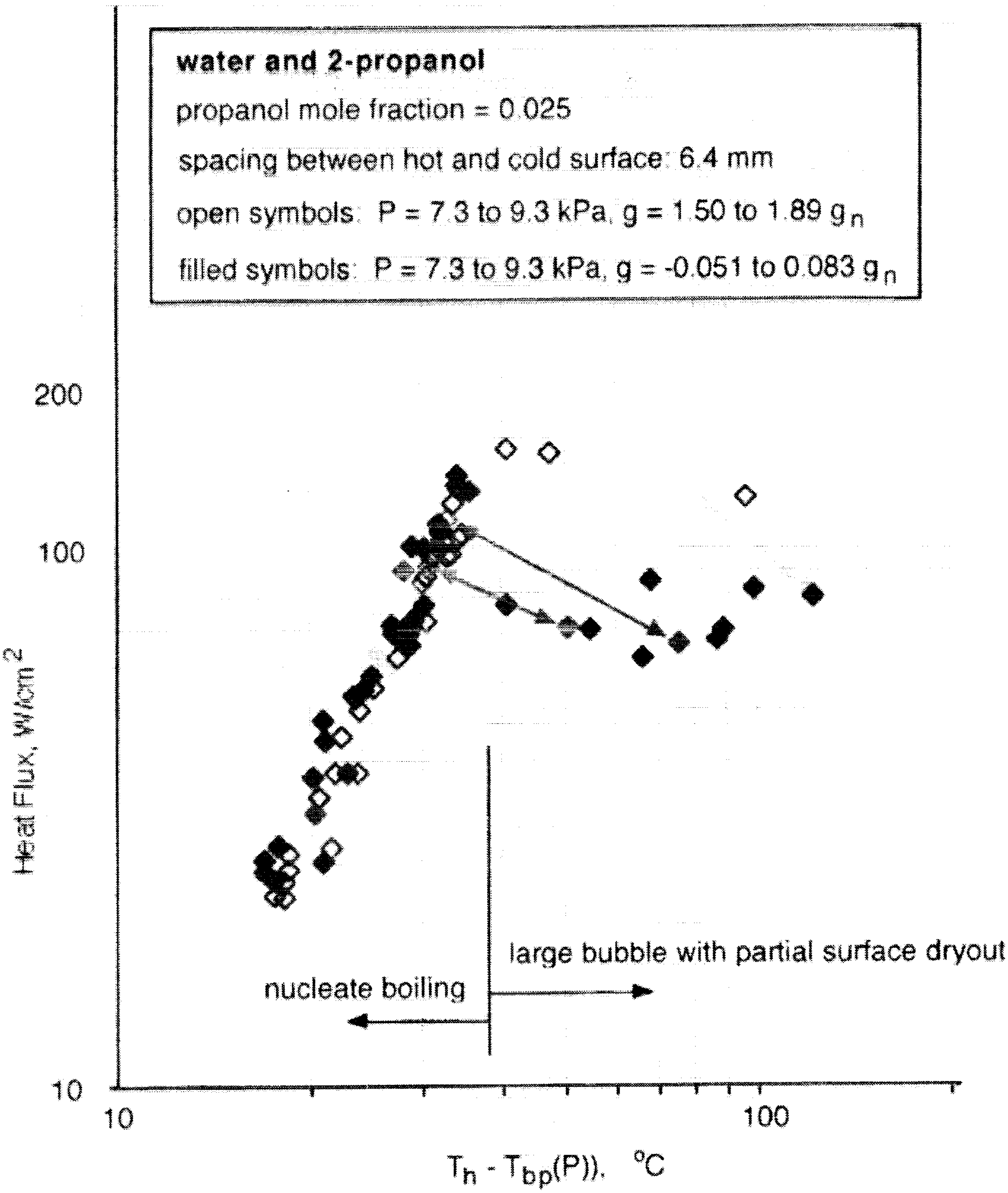
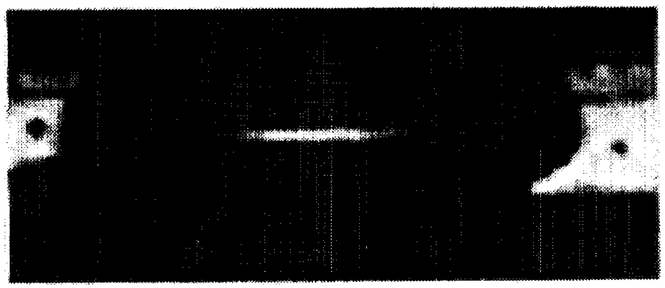
day 3, manuever 21



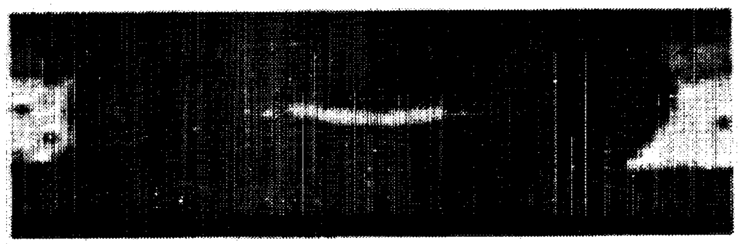

water and 2-propanol
propanol mole fraction = 0.025
spacing between hot and cold surface: 6.4 mm
open symbols: P = 7.3 to 9.3 kPa, g = 1.50 to 1.89 g n
filled symbols: P = 7.3 to 9.3 kPa, g = -0.051 to 0.083 g n
200
100
10
Heat Flux, W/cm 2
large bubble with partial surface dryout
nucleate boiling
10
100
Th - Tbp(P)), °C

Transition from low g to high g, day 3 maneuver 21

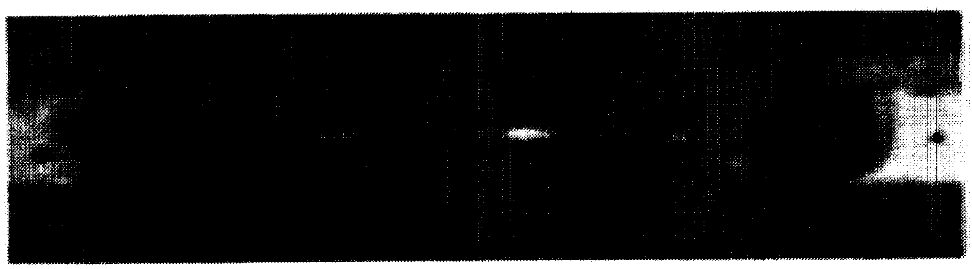
Gap = 6.4 mm, water and 2 propanol at x = 0.025



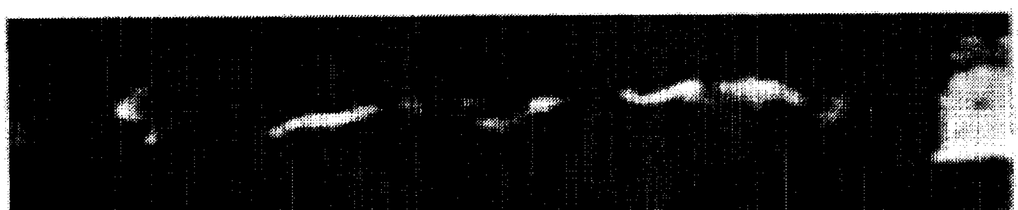
t = 18.485 s



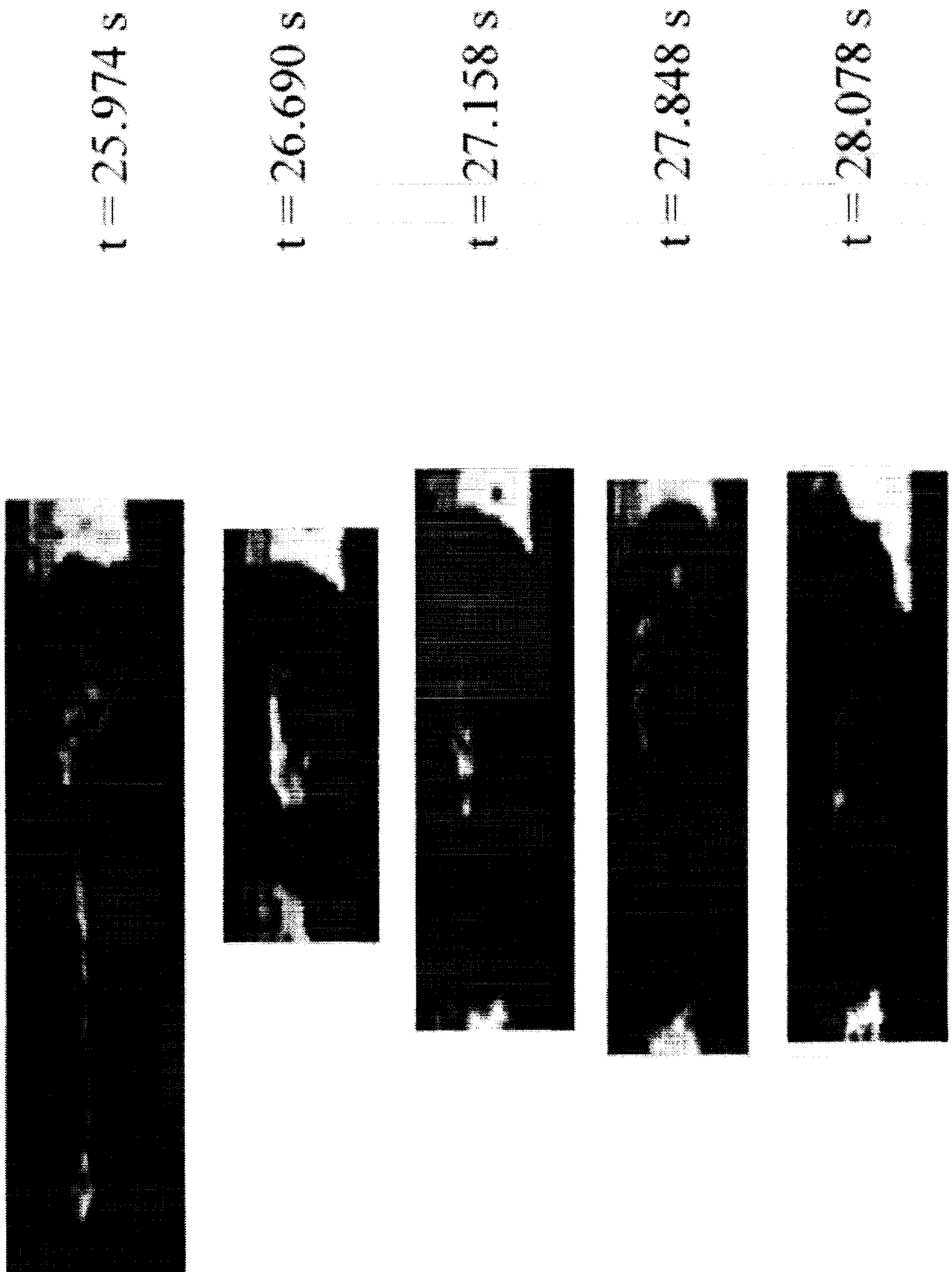
t = 21.018 s

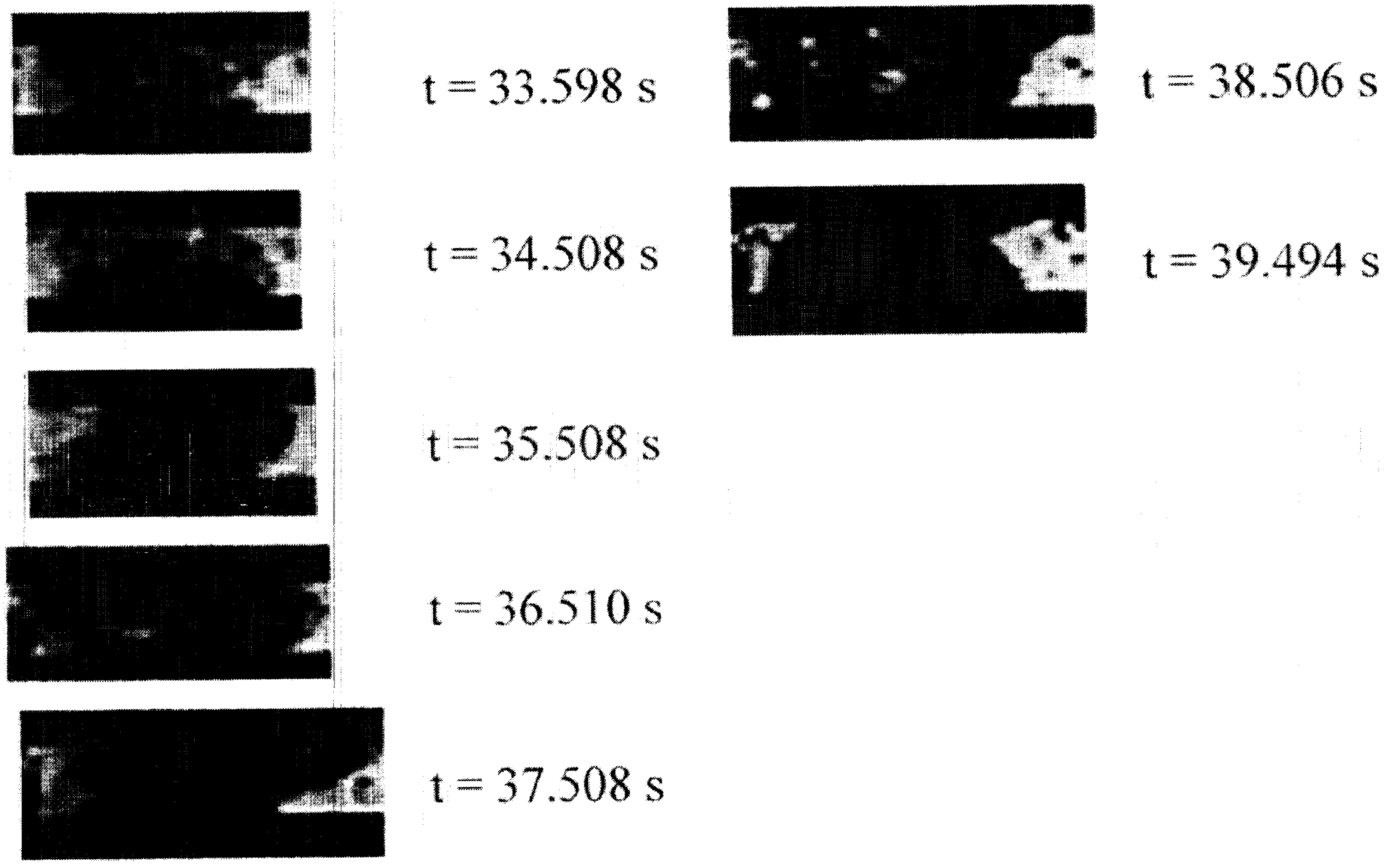


t = 22.026 s



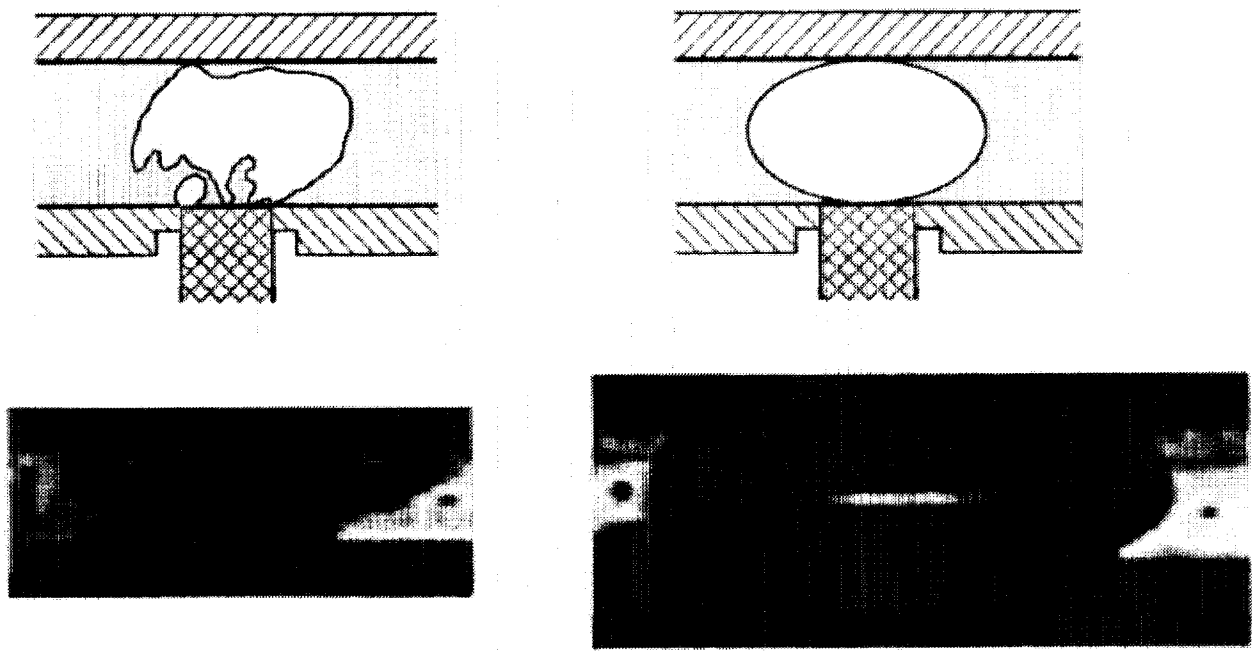
t = 23.414 s


t = 25.974 s
t = 26.690 s
t = 27.158 s
t = 27.848 s
t = 28.078 s


t = 33.598 s
t = 34.508 s
t = 35.508 s
t = 36.510 s
t = 37.508 s
t = 38.506 s
t = 39.494 s

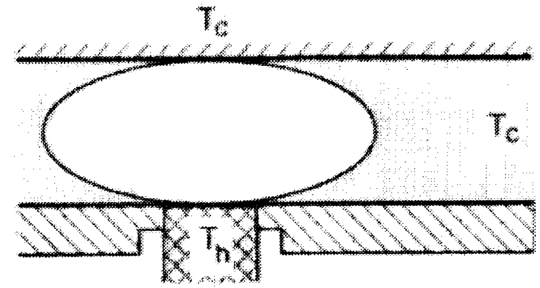
Results of Experiments

- Two boiling modes observed:
  - Nucleate boiling
  - Large stationary bubble with partial surface dryout



- Phase morphology and heat transfer characteristics determined for each type

Subsequent Work



- Development of model of near-bubble transport including
  - Wall conduction
  - Bulk fluid motion
  - Microlayer transport between interface and walls
  - Marangoni effects

- Comparison of experimental data with model predictions for 1g and reduced g results
- Analysis of parametric effects using model

- Experiments with other aqueous mixtures